February 18, 1886.

Professor G. G. STOKES, D.C.L., President, in the Chair.

The Presents received were laid on the table and thanks ordered for them.

The following Papers were read:—

I. "Observations on the Radiation of Light and Heat from Bright and Black Incandescent Surfaces." By MORTIMER EVANS, M.Inst.C.E., F.R.A.S. Communicated by Lord RAYLEIGH, M.A., D.C.L., F.R.S. Received February 3, 1886.

In the course of an investigation into the nature of carbon filaments, such as are ordinarily used in the construction of incandescent lamps, my attention was arrested by certain variations in the amount of light emitted from filaments which were, to the best of my belief, of similar nature and composition, but which, when tested under precisely similar conditions, gave the most anomalous results. I was also struck with changes which occurred to a greater or less degree in the light yielded by certain lamps when re-tested subsequent to a shock of over-incandescence, or long continued hard running at a high temperature; the light yielded after this occurrence (indeed the light yielded by any lamps that had been much used) I found to be invariably lessened both in quantity and brightness, and to require a considerable increase in the energy supplied to it to produce from the same filament the light it originally gave. After seeking vainly to account for these irregularities from structural differences in the carbon filaments themselves, and after testing and re-testing many carbons made in a variety of ways, both by myself and others, it occurred to me that the composition or structure of the carbon itself, of which the filaments were made, might have really little to do with the discrepancies and changes I had noticed.

All the carbons I had tried gave in turn the most irregular results, and although some of these were porous, and some dense and compact, the light emitted from any one of them per unit of surface for each unit of electrical energy supplied to it was very varied and uncertain, and did not appear to follow any condition of the porosity or denseness of the filament itself.

All the carbons in turn gave the same light per unit of surface

when raised to the same incandescence, but the energy required to produce this light, or raise the filament to this incandescence, varied sometimes in a remarkable way. At times a filament was found which, with 2 watts or volt ampères passing through it, would yield the light of the standard candle. And again, with other filaments it sometimes occurred that no less than 5 volt ampères were required to produce this light.

On collating a number of these observations, and comparing the filaments themselves with their various testings, I noticed, I thought, some difference in the outward appearance of those filaments which had tested well and those that had required any large amount of energy to give a satisfactory light, and, following up this idea, I soon became convinced that it was to this surface appearance or condition that the whole question of economical light giving or otherwise might be traced. All the filaments, it appeared, whose surfaces were of a dull black required the larger amounts of energy to yield the usual unit of light, while from those filaments with even moderately bright surfaces the light of the standard candle could be obtained for an expenditure of energy surprisingly less. To ascertain with greater certainty if this idea were correct, I prepared a number of carbons made from a vegetable fibre which, though yielding a somewhat porous carbon, was strong and uniform in texture.

Having selected two filaments as like each other as the eye could determine, and having ascertained by careful measurement that they were both of exactly the same length and diameter, and therefore of equal surface, I subjected each carbon in turn to the action of an electrical current in a hydrocarbon atmosphere, so regulating the current as to maintain the carbon filament at a white heat in the vapour until a sufficient deposit of carbon upon its surface was obtained.

To provide for the deposit of carbon upon the one filament being as dull a black as possible, I used for the depositing medium an atmosphere of ordinary coal-gas drawn from a domestic burner. A large glass jar was filled with this, and a constant current of the cold gas kept circulating through it during the deposit, and the resulting surface was all that could be desired. It had all the appearance of being coated with lampblack, but the coating was quite permanent, and did not brush off, or even soil the fingers in handling.

On the other of these two filaments I now deposited carbon of a bright silvery appearance in marked contrast with the dull black of that just described, and this deposit I found I could readily effect by using as the depositing atmosphere the very hot vapour of almost any hydrocarbon having a high boiling point, though from the porous nature of the carbons I was using I did not get the surface as brilliant as I subsequently obtained it from smoother carbons.

This filament was then mounted on platinum electrodes, as the other had been, enclosed in a similar glass globe, and exhausted of air, the vacuum being carried to about the $\frac{1}{1000000}$ of an atmosphere.

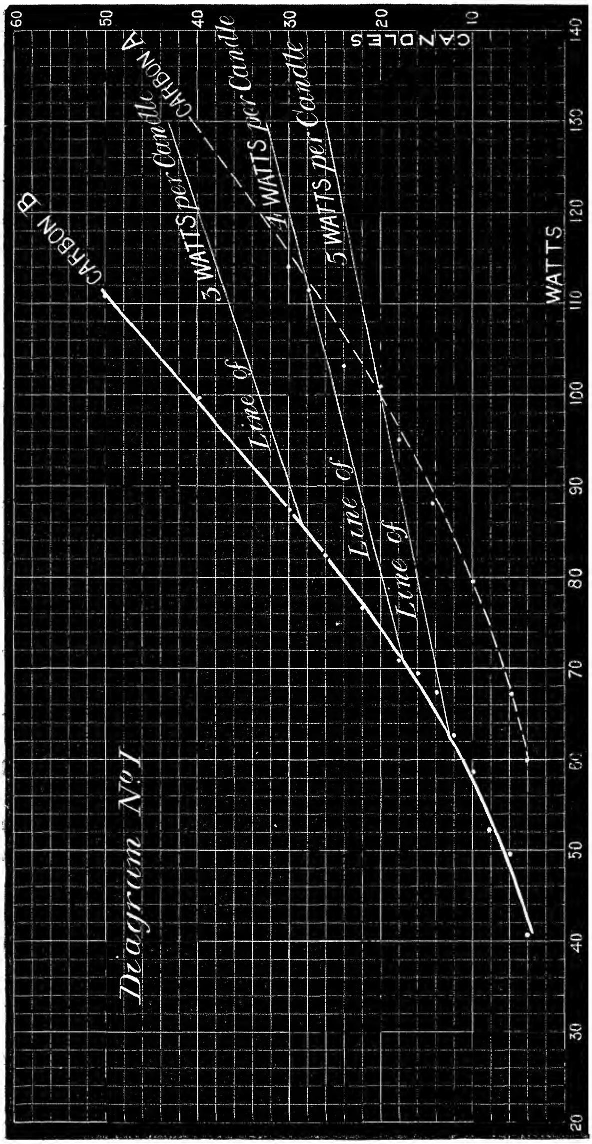
The remeasurement of these carbon filaments subsequent to the reduction of the carbon on their surfaces, showed no perceptible increase in their diameter, the deposit of carbon which had been added being in all likelihood less than the ten thousandth of an inch in thickness, and the surface areas of each filament still remained practically equal in all respects.

Having now two carbon filaments with which a comparative test might be made, and in which the conditions were in all respects identical, except in that of surface condition or polish, the one being like soot and the other like silver, I passed a series of known electrical currents through each in turn, registering the light produced against a standard candle burning 120 grains per hour in a good photometer provided with a sliding screen.

In Table No. I, Carbon A, are shown the testings of the blackened filament, and in Table II, Carbon B, those of the filament which was made bright. In diagram No. 1 may be seen the plotting of these results and their relative curves. The dotted curve marked Carbon A shows the testings of the black filament, and the curve marked with a plain hard white line, Carbon B, gives the testings of the filament which was bright. The horizontal divisions in the diagram give the watts or volt ampères of energy passing through the filament, and the perpendiculars mark the corresponding candle powers. From these tests it may be noticed that with two carbon filaments identical in all respects but in that of surface polish or brightness, the blackened filament required no less than 100 watts to keep its surface at an incandescence yielding 20 candles, whilst the filament with the bright surface was kept at the same incandescence, and gave an equal light with 74 watts only, also that each filament when consuming an energy of 4 watts per candle, that which was blackened required no less than 113 watts of energy to effect this (besides having its surface incandescence strained to yield 28 candles), while the bright filament with 71 watts only effected the same economy, viz., 4 watts only per candle, and had to give from its surface only $17\frac{3}{4}$ candles.

These results satisfied me that the condition of the carbon surface was wholly the cause of the large differences shown by these curves, and I determined therefore to carry out a more extended series of tests with carbons about which I knew nothing.

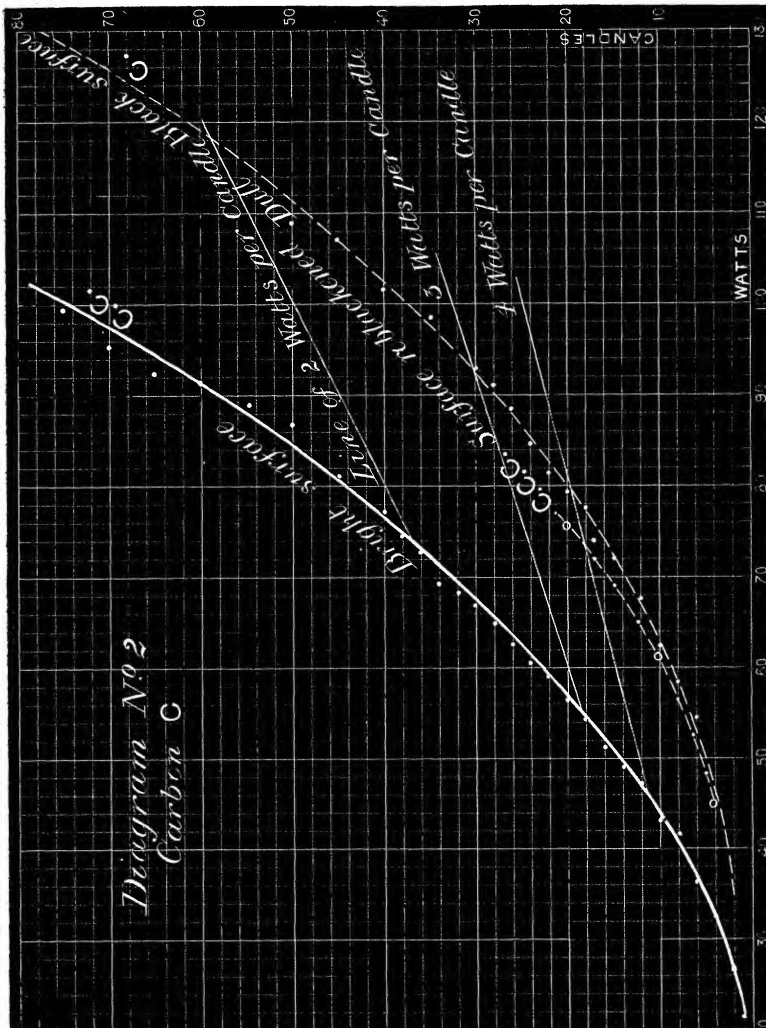
For this purpose, therefore, I procured two carbons of foreign manufacture, but by whom made I did not know. The following were their chief characteristics. The carbons were very nearly square in section, and appeared before carbonising to have been sliced from some homogeneous material like parchment paper.

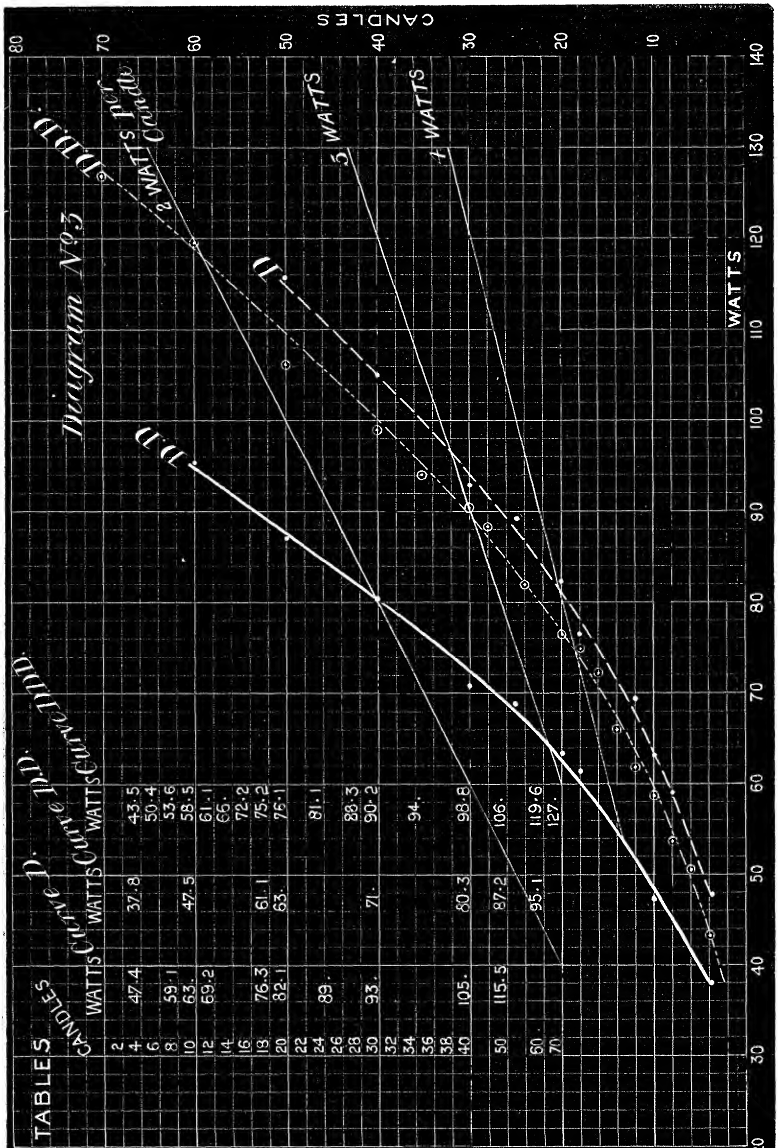


They were both, I found from careful measurements, of precisely the same dimensions and surface area, and each presented the same dull dead black surface; the carbon itself appeared exceedingly dense and hard. Testing these filaments as I procured them, I placed them in bulbs and exhausted as before.

Tables III and VI give the photometric tests of these carbons as I procured them, and diagrams 2 and 3 show the plotting of these tests. I have marked these filaments C and D, the black dotted line in diagram 2 being the curve for filament C, and the black dotted line in diagram 3 that for filament D.

In these two curves the extreme uniformity with which these carbons tested is worthy of notice, the one giving nineteen and a half candles and the other twenty for the eighty watts supplied to each,





CANDLES	WATTS Curve D.	WATTS Curve DD.	WATTS Curve DDD.
2			
4	47.4	37.8	43.5
6			50.4
8	59.1		53.6
10	63.	47.5	58.5
12	69.2		61.1
14			66.
16			72.2
18	76.3	61.1	75.2
20	82.1	63.	76.1
22			
24	89.		81.1
26			
28			88.3
30	93.	71.	90.2
32			
34			94.
36			
38			
40	105.	80.3	98.8
50	115.5	87.2	106.
60		95.1	119.6
70			127.

which not only well inside any error of observation, but is in great measure a sufficient proof of the extreme equality of the areas of their radiating surfaces.

I now dismounted these filaments and subjected them to incandescence in the hot hydrocarbon vapour as before with carbon B. The result was highly satisfactory, as they both took a surface much brighter than carbon B had done. Again remounting them and exhausting, they were placed in the photometer as before. The results are given in Tables IV and VII, and the curves from these tables are shown by the bright hard lines CC and DD, diagrams 2 and 3. These curves appear fully to bear out the assumption arrived at in the former tests, Tables I and II, and the improvement in light radiation per unit of energy is especially marked in the case of filament C, where it may be noticed that at 2 watts of energy per candle of light the same filament in its black condition was strained to yielding sixty candles nearly, while in its polished state it had only to yield thirty-seven, and still be as economical in its electrical energy as before. The same filament at 3 watts per candle, when black, had to give off 31 candles, equal to 270 candles per square inch of its surface, while in its polished state it required to give only 18 candles to equal 3 watts per candle, and its surface was strained only to the extent of 155 candles per square inch. It is certain, therefore, that its lasting power with its surface bright would be many times greater at the foregoing expenditure of energy than in its black condition.

As the filaments were still unbroken and appeared capable of yet another test, I resolved to attempt the reblackening of them, and to ascertain if possible if the test-curve under these conditions would again revert to its former position, but I had now to reblacken over the bright surface which could not be removed. The filaments were again successfully dismounted, and with some difficulty again reblackened over their former polished surfaces.

They were now tested, as is shown in Tables V and VIII, and the corresponding curves are given in diagrams 2 and 3, marked CCC, DDD. The recession of the curves was in both cases nearly complete, any difference being fully accounted for by the incomplete reblackening of the carbon surface.

In carrying out these experiments I much regret not having made the necessary arrangements for simultaneously testing both the heat and light emitted from each filament in its blackened and bright condition. I have little doubt the loss of efficiency when black was due to the energy supplied being radiated in large quantities as heat waves from the blackened surfaces, which these surfaces when bright would not permit. This radiation of heat, however, which had not been converted into light by emission from a bright surface was abundantly manifested in the handling of the lamps. The incandescent globe containing the bright filament could at all times be readily held in the hand even when giving its maximum of light, while the heat radiated from the filament when its surface was blackened was most

intense, and not only caused at times severe burns, but occasionally would even char the little paper labels attached to the glass.

I also regret not having dissipated by a powerful current the black carbon deposited over the bright surface in the last case, as an increase of economy in working and light-giving should have resulted, and this would have been the more interesting as ordinarily it is just the other way; as soon as by overheating or long use the polished surfaces of our best lamps are injured, so surely is there an increased waste of energy, and hence the extreme difficulty of preserving lamps made for use as standards for any long period.

From these results it appears probable that the attainment of economical high E.M.F. lamps of ordinary sizes may be very difficult, as what would be a high E.M.F. lamp with a black surface would be a low E.M.F. lamp were this black surface made bright; the energy required being less, both the E.M.F. and current would have to fall. The desire, therefore, for high E.M.F. lamps should be met not by a supply of black wasteful filaments, but more properly by economical lamps of greatly increased size and candle power, or by lamps of a smaller candle power run two or more in series.

DIAGRAM 1.

	Carbon A. Table I.			*Carbon B.* Table II.		
Candles.	Volts.	Amp.	Watts.	Volts.	Amp.	Watts.
4	53·5	1·12	60	38·5	1·05	40·4
6	56	1·2	67·2	42	1·18	49·5
8	..	..	..	43	1·23	52·4
10	60·5	1·32	80	45	1·30	58·5
12	..	..	..	46·5	1·35	62·5
14	63	1·4	88·2	48	1·41	67·6
16	..	..	..	48·5	1·43	69·3
18	65	1·46	94·9	49	1·45	71·0
20	66·5	1·52	101			
22	..	..	..	50·5	1·52	76·7
24	67	1·54	103			
25						
26	..	..	..	52	1·58	82·1
28	69	1·62	111·7			
30	69	1·65	113·8	53	1·65	87·7
35						
40	74	1·80	133·2	56	1·78	99·7
45						
50	..	..	..	58·5	1·9	101
55	77	1·95	181			
60	..	..	..	62	2·05	127

DIAGRAM 2.

Carbon C.

	Curve C. Table III.			C.C. Table IV.			C.C.C. Table V.		
Candles.	Volts.	Amp.	Watts.	Volts.	Amp.	Watts.	Volts.	Amp.	Watts.
4	45	0·86	38·7	34	0·95	32·7	39	1·16	45·2
6	52·5	1·04	54·6	35	1·02	36·2			
8	54	1·08	58·3	38	1·08	41·0			
10	56	1·12	62·7	39	1·12	43·7	44·5	1·38	61·4
12	58	1·17	67·8	40	1·17	47·3			
14	59	1·22	71·9	41	1·20	49·2			
16	60	1 23	73·8	42	1·22	51·2			
18	61	1·27	77·4	43	1·26	54			
20	62	1·28	79·7	44	1·28	56·3	49·5	1·53	75·7
22	63	1·3	81·9	44·5	1·33	59			
24	64	1·32	84·5	45	1·35	60·7			
26	65	1·36	88·4	46	1·36	62·5			
28	66	1·38	91·0	46·8	1·40	65·4			
30	66·5	1·40	93	47	1·47	67·2			
35	68	1·46	99·2						
40	69	1·48	102	49·5	1·54	76·2			
45	70·5	1·52	107	50	1·60	80·8			
50	71	1·54	109	52	1·67	86·8			
55	72	1·58	113	52·5	1·70	89·1			
60	73·5	1·62	119	52·8	1·73	91·3			

DIAGRAM 3.

Carbon D.

	Curve D. Table VI.			D.D. Table VII.			D.D.D. Table VIII.		
Candles.	Volts.	Amp.	Watts.	Volts.	Amp.	Watts.	Volts.	Amp.	Watts.
4	46·5	1·02	47·4	37·3	1	37·8	34	1·28	43·5
6	..	..	..	..	..	..	36	1·4	50·4
8	51	1·16	59·1	..	..	..	37	1·45	53·6
10	52·5	1·20	63	42	1·13	47·8	38·5	1·52	58·5
12	54·5	1·27	69·2	..	..	..	40	1·54	61·6
14	..	..	..	..	..	..	40·5	1·62	66
16	..	..	..	..	..	..	42	1·72	72·2
18	57	1·34	76·3	47	1·30	61·1	43	1·75	75·2
20	58·3	1·40	82·1	47·8	1·32	63	43	1·77	76·1
22									
24	..	..	..	..	..	..	44·5	1·84	81·8
25	61	1·46	89·0						
26									
28	..	..	..	..	..		46	1·92	88·3
30	62	1·50	93	50	1·42	71	46·5	1·94	90·2
35	..	..	..	..	..	..	47	2	94
40	65	1·62	105	52·5	1·53	80·3	48	2·06	98·8
45									
50	68	1·70	115	54·2	1·60	87·2	50	2·12	106
55									
60				57	1·67	95·2	52	2·3	119·6

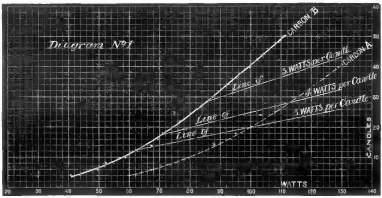


Diagram Nº1
CARBON B
CARBON A
Line of
3 WATTS per Candle
Line of
4 WATTS per Candle
Line of
5 WATTS per Candle
CANDLES
WATTS
60
50
40
30
20
10
20
30
40
50
60
70
80
90
100
110
120
130
140

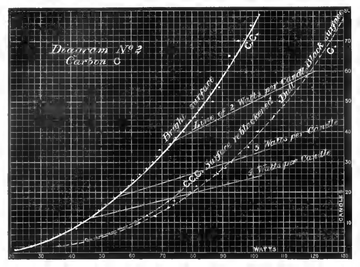
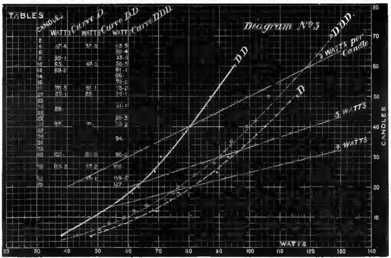


Diagram Nº 2
Carbon C
C.C.
C.
Bright surface
Line of 2 Watts per Candle
Black surface
C.C.C. Surface reblackened Dull
3 Watts per Candle
4 Watts per Candle
CANDLES
WATTS
10
20
30
40
50
60
70
80
20
30
40
50
60
70
80
90
100
110
120
130



TABLES
Diagram No. 3

CANDLES	Curve D. WATTS	Curve D.D. WATTS	Curve D.D.D. WATTS
2			
4	47·4	37·8	43·5
6			50·4
8	55·1		53·6
10	63·	47·5	58·5
12	69·2		61·1
14			66·
16			72·2
18	76·3	61·1	75·2
20	82·1	65·	76·1
22			
24	89·		81·1
26			
28			86·3
30	93·	71·	90·2
32			
34			
36			94·
38			
40	105·	80·[illegible]	98·6
50	115·5	87·2	106·
60		95·1	119·6
70			127·

D
D.D
D.D.D.
7 WATTS per Candle
5 WATTS
4 WATTS
WATTS
CANDLES
20
30
40
50
60
70
80
90
100
110
120
130
140
10
20
30
40
50
60
70
80